Experimental research on the icing progress of insulators at Xuefeng Mountain Natural Icing Test Base

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***Abstract*—The environmental parameters can be controlled and the ice test is not limited by season in the artificial climate chamber. Therefore, the experimental research on the icing progress of insulators is mainly carried out in the artificial climate chamber. However, there are considerable differences between the icing formed under artificial environment and that formed under natural environment. To explore the characteristics of the icing growth under natural environment, the different type of insulators were suspended on glaze tower at Xuefeng Mountain Natural Icing Test Base and the key factors affecting the icing growth were analyzed. The research results indicate that icing is influenced by many factors, such as the meteorological parameters, the arrangement positing and structure of insulator. The lower of temperature and the greater of wind speed, the more icing accretion on the surface of insulator will be. The ice mass of insulators and the thickness of insulator surface grow nonlinearly with the increasing of time, while the growing degree of ice thickness slows down with the increasing of time. Icing of insulators arranged on the windward side is somewhat more serious than that arranged on the leeward side. Under natural condition, ice mainly exits on windward side of insulator and there is almost no ice on leeward side.**

***Key words*—Natural icing test base, insulator icing, icing growth, mass of ice, thickness of ice.**

I. Introduction

In recent years, “EI Nino” and “La Nina” and other extreme weather events frequently occur, which result in transmission lines covered by ice. When ice load exceeds the design value of transmission lines, tower falling down, icing flashover and even large area power outages will happen. Icing is a serious threat to the safe operation of power system. China is one of the countries which are frequently attacked by icing [1-2]. In 1954, China recorded the first icing disaster of transmission lines. In the following decades, icing accidents have reached up to thousands of times [3]. In particularly, the freezing rain, rare in the history, attacked the south of China in early 2008. An average ice thickness of transmission lines was up to 30 mm and the maximum icing thickness was more than 100 mm, which was far more than the design value. This icing disaster brought great economic losses.

So far, the domestic and foreign scholars have carried out extensive studies on the icing accretion on the surface of conductor and the icing forecast models, mainly based on meteorological parameters and characteristics of collision, have been built [5-11]. However, the shape and structure of insulators are complex. Therefore, it is difficult to build a model to predict the icing growth of insulators. Literatures [12-13] experimentally research on the icing process of LXP-160 and composite insulators under different environment parameters and analyze the influence of these parameters, such as temperature, mean diameter of water droplet and wind velocity, etc.

Icing is a common natural phenomenon. There are four meteorological parameters affecting the outdoor insulator icing, namely, air temperature, wind velocity and wind direction, super-cooled water droplet diameter and liquid water content in the air. Nevertheless, insulators at service are also influenced by other factors, such as the local geography, altitude, condensation level, the structure of insulator, electric field strength and load current, etc. [14-18]. Due to natural conditions, test equipment and other reasons, the current study for icing is mainly carried out in artificial climate chamber rather than in field. Whether or not the results obtained in artificial climate chamber should directly guide the design of external insulation is worth discussing. This paper experimentally studies the icing accretion on the surface of insulators at Xuefeng Mountain Natural Icing Test Base (XMNITB) and analyzes the factors influencing icing.

II. Test Base And Specimens

A. Xuefeng Mountain Natural Icing Test Base

The field tests are conducted at XMNITB (seen Figure 1) where there are the characteristics of the typical local topography and local meteorology with 150 days icing period a year, more than 1800 mm rainfall per year, maximum wind velocity of 35 m/s, the lowest temperature of -15 ℃ and maximum glaze ice thickness of up to 500 mm. The two glaze towers (9 m (width)×9 m (length)×9 m (height)) are set up to suspend different types of insulator strings and conductors at XMNITB.

Figure 1 Xuefeng Mountain Natural Icing Test Base

B. Test specimens

As shown in Figure 2, different types of insulator strings are suspended at the top of glaze tower, which include three porcelain insulator strings with seven units and two glass insulator strings with seven units. Each of insulator strings is fixed on the glaze tower by the drawing force transducer. Four types of composite insulators with different shed configurations are arranged on the bottom of the glaze tower. The basic technical parameters and structure diagrams of all insulators are shown in Table 1 and Figure 3. In Table 1, *H* is the length of insulator, mm; *L* is the creepage distance, mm; and *D* is the diameter of the shed, mm. PortLog is used to measure the meteorological parameters during the ice period, including: temperature, relative temperature, wind speed and direction, atmospheric pressure, and so on.

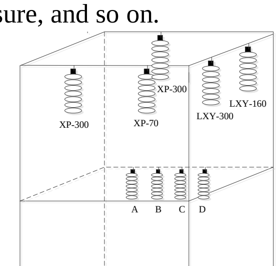
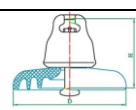
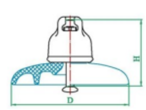
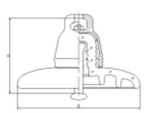
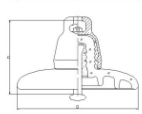


Figure 2 Diagram of insulator strings arrangement

Table 1 Dimensions and profiles of porcelain and glass insulators

Types	*D*	*H*	*L*	Profile
XP-300	320	195	370	
XP-70	255	146	295	
LXY-300	320	195	485	
LXY-160	280	170	400	

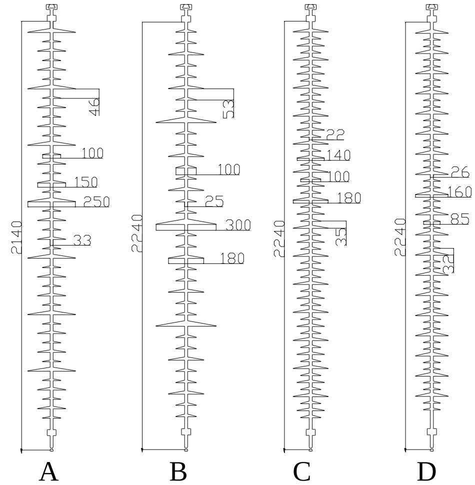


Figure 3 Profiles of composite insulators

III. TEST RESULTS AND ANALYSIS

A. Meteorological parameters during the ice period

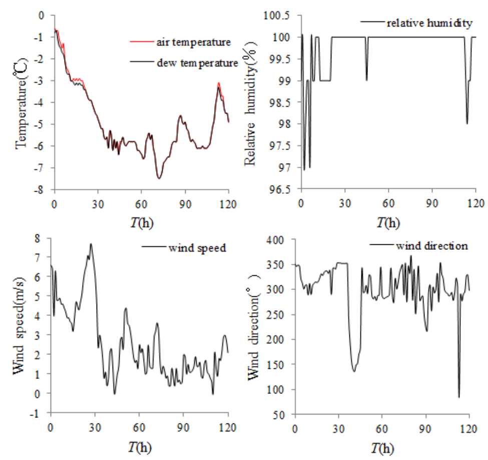
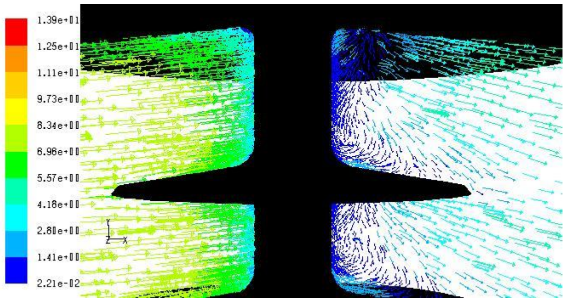


Figure 4 Meteorological parameters during the ice period

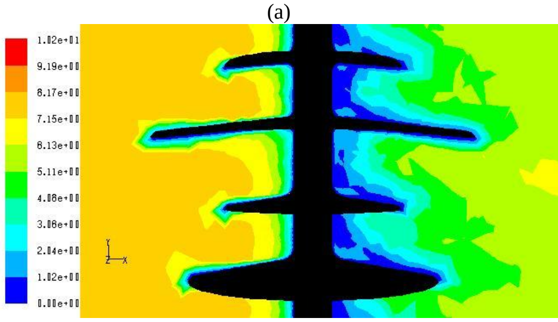
When the air temperature dropped to below 0 ℃, ProtLog started to record the data of meteorological parameters for the following 120 hours. Figure 4 shows the change tendency of air temperature, dew temperature, relative humidity, wind velocity and wind direction with the time increasing during the icing period.

Although air temperature was somewhat higher in initial and final stage, it was always below 0℃ throughout the icing period. Due to effect of wind, temperature declines linearly at early stage and dropped to -7.5℃ after 70 hours. The dew temperature had the same change trend with air temperature. Although relative humidity fluctuated at the beginning, it remained at 100% in the following rest of the icing period and provided sufficient super-cooled water droplets for the atmospheric structure icing. Wind velocity was higher at the early stage and the maximum reached up to 7.7m/s. Wind velocity fluctuated with alternative day and night. The overall trend was that wind speed during the night was higher than that during the day. During most time of the ice period, wind blew from the northwest and north. When it blew from southeast, it blew at lower speed and lasts only a short time.

B. Air flow field characteristics and water droplets collision characteristics near insulator



(a)



(b)

Figure 5 (a) Velocity vectors near the surface of insulaotor
(b) Velocity magnitude near the surface of insulator

This paper obtains velocity magnitude, velocity vectors and water droplets collision characteristics near the surface of the insulator for Type C without icing by using CFD software to simulate air flow field. As shown in Figure 5, a boundary layer, changing with gradient, exists on the surface of insulator. Due to the viscous effect, air velocity near the surface of insulator approximates zero, then increases gradually along with normal direction of the wall. Air flow velocity drops greatly near the bottom surface of insulator, where there is obvious vortex resulting in icing.

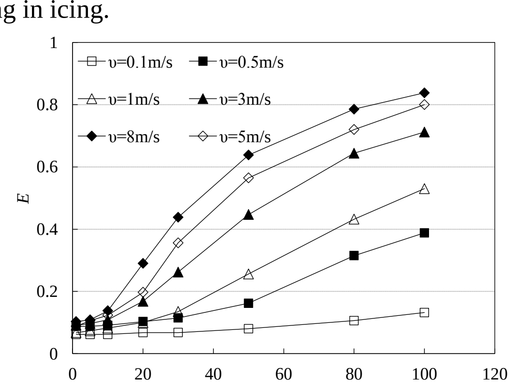
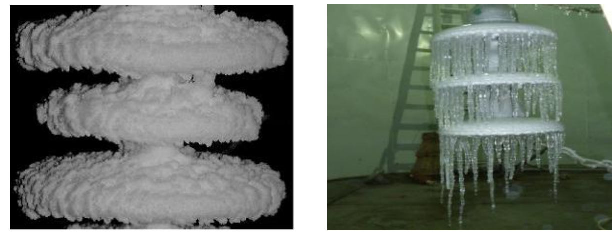


Figure 6 Influence of wind velocity on E

As shown in Figure 6, the collision efficient (E) increases with the increase of mean diameter of water droplet (d_{eq}) or wind velocity (v). When d_{eq} is less than 10 μm, E changes slowly. While d_{eq} is more than 10 μm, E changes quickly. This is mainly because that with the increase of wind velocity, the inertial effect of water droplets is greater than the air drag force, and the number of water droplets colliding with the surface of insulator increases.

C. Difference in icing appearance



(a) Rime (b) Glaze

Figure 7 Appearance of ice-covered insulator in artificial climate chamber

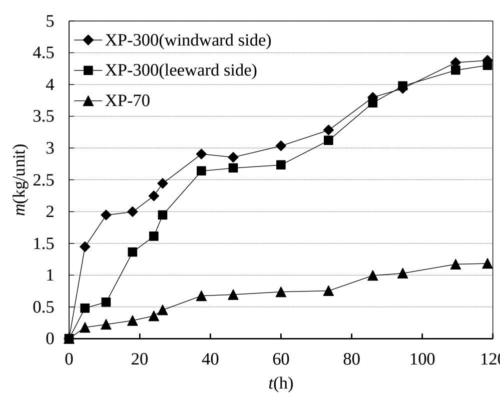
(a) Windward side (b) Leeward side

Figure 8 Appearance of ice-covered insulatorat XMNITB

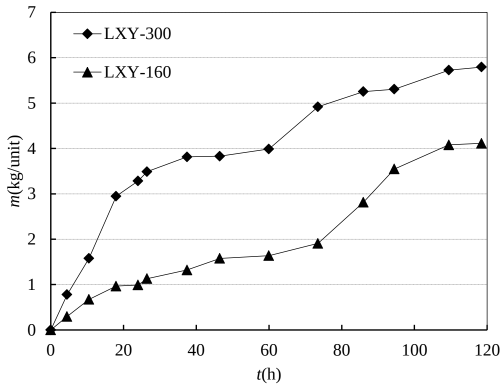
It can be seen from Figure 7 and 8 that the different test environments have a great influence on the icing appearance. As shown in Figure 7, two types of icing (glaze and rime) are uniform in the artificial climate chamber. However, for field experiment, it is totally different. As shown in Figure 8, ice mainly exists on windward side of insulator and there is almost no ice on leeward side. There is a clear dividing line between the both. Although a variety of meteorological parameters can be simulated and the ice tests are not limited by season in artificial climate chamber, using the results obtained to guide engineering design still has many limitations. Therefore, carrying out the field tests is an indispensable part.

D. Growth of ice mass

The ice mass of four types of insulator strings are measured by drawing force transducer and the results are shown in Figure 9.



(a)



(b)

Figure 9 Relationship between the ice mass of insulators and the icing time. (a) porcelain insulator strings; (b) glass insulator strings

According to the results shown in Figure 9, the following conclusions can be drawn.

(1) The ice mass of insulator strings grows nonlinearly with the increasing of time, while the growing degree is varied with the increasing of time. Within 40 hours from the beginning of icing, the ice mass grow rapidly. The ice mass of insulators per unit is up to 2.9, 2.6, 0.67, 3.81, 1.32 kg, respectively, accounting for 66.4, 61.4, 47, 65.8, 32.2 ％ of total ice mass. At this stage, the temperature decreases from 0 to -6 ℃ and wind speed is more than 3 m/s. Due to low environmental temperature and high air humidity, a part of super-cooled water droplets are frozen on the surface of insulators, which resulted in the increase of the roughness. When a number of super-cooled water droplets carried by the wind collide with insulators, the ability to capture the water droplets is enhanced. The wind speed accelerates heat exchange process and water droplets freeze rapidly. With the increase of time, the ice growth rate slows down. The reason might be that the windward side of insulator has been bridged by ice after 40 hours, which results in the change of turbulent flow field near insulator and the decrease of *E*.

(2) For porcelain insulator strings with same structure, Icing of insulators arranged on the windward side is somewhat more serious than that arranged on the leeward side. This is mainly because that due to effect of the rest of insulator strings and glaze tower, the airflow and water droplets lose a part of momentum energy causing the speed decrease of the air flow and water droplets, which results in the decrease of collision coefficient. As time increases, icing changes the shape of the insulator and *E* tends to be the same. Therefore, the difference of the ice mass becomes smaller and smaller and finally tends to be saturated.

(3) There is considerable difference in the ice mass between two types of porcelain insulator stings. The ice mass of XP-300 is as high as 4.3 kg, while there is only 1.2 kg for XP-70. However, the ice mass of LXY-300 and LXY-160 is 5.8kg and 4.1 kg, respectively, with a difference of 1.7 kg. The reason might be that the larger diameters of the shed of XP-300 and LXY-300 with the larger windward area could capture more super-cooled water droplets leading to more severe icing.

E. Growth characteristics of ice-covered insulators

To analyze the growth characteristics of ice-covered insulator over time, the icing period is averagely divided into three stages, namely the early stage, the middle stage and the later stage. As is shown in Figure 10, this paper selects the extended length of icicle attached on the surface of insulator (l), the ice thickness of the shed (d_0) and the ice thickness of insulator's leeward side (d_1) as ice characteristics of ice-covered insulators.

Figure 10 Schematic diagram of experimental measurement

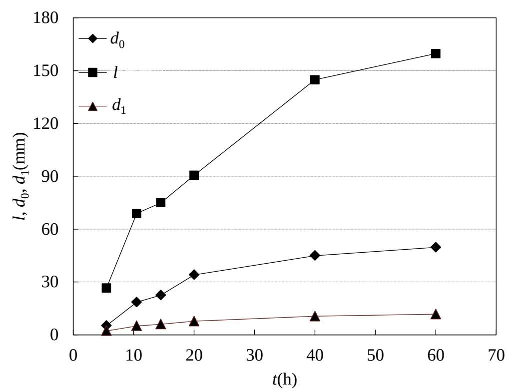
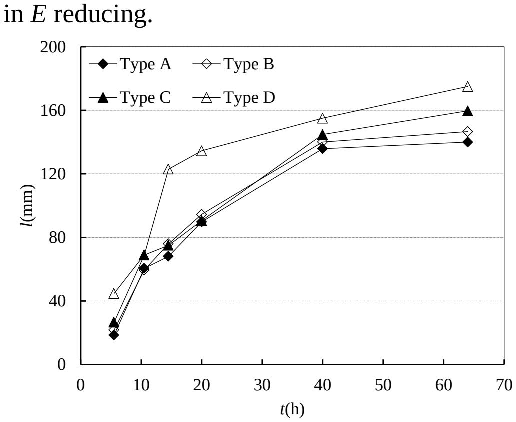
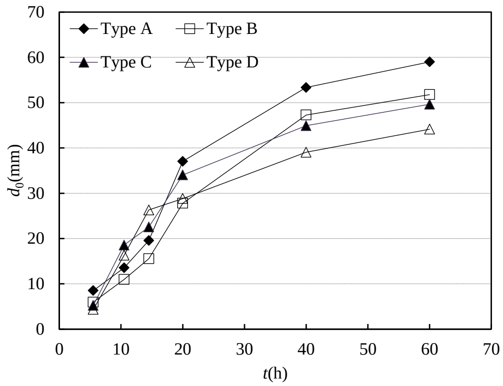


Figure 11 Relationship between ice characteristics of ice-covered insulators and icing time.

There is a similar ice growth process among four types of composite insulators, so the ice characteristics of Type C are only chosen to be analyzed. As is shown in Figure 11, d_0 increases by 34.05, 10.87 mm and 11.75 mm and d_1 increases by 7.72, 2.83 mm and 2.31 mm at each stage, respectively. It is obvious that the ice growth rate of d_0 is significantly faster than that of d_1 and then both grow slowly. This can be explained by the fact that the shape of insulators is changed by ice, which results in *E* reducing.



(a)



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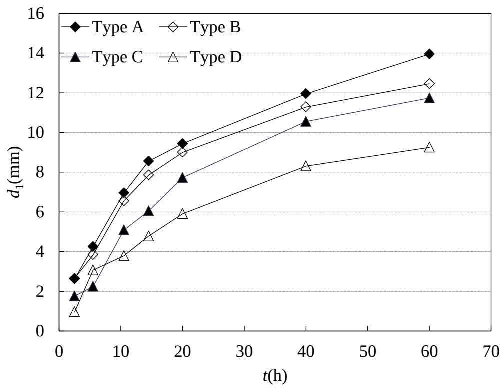

(c)

Figure 12 Relationship between ice characteristics of ice-covered insulators and icing time. (a) l; (b) d_0; (c) d_1.

According to Figure 12, it can be observed that:

(1) From Figure 12(a), it can be seen that the increase of l is nonlinear. At the initial period of icing, the extended length of type A~C is 89.76, 94.5 mm and 90.56 mm respectively, however, Type D gain a faster increase of 134.5 mm. The simulation analysis of previous research concludes that E decreases with increasing of top surface inclination and diameter of shed [19].The disturbance degree increases with the shed diameter increasing, which results in increasing the bend degree of the flow line, enhances the drag force of water droplet applied by the flow and reduces E. As icing continues, the shape of insulator has been changed and the equivalent diameter of insulator is larger. Thus, E further reduces. Then, l tends to be saturated, which is also affected by the decrease of wind speed in the later stage.

(2) As shown in Figure 12(b), for all four types of composite insulators with different shed configurations, d_0 will first increase with an increase in the icing time, and then change very slowly. At initial period of icing stage, d_0 of different type insulators grows rapidly with increasing by 37.05, 27.8, 34.05 mm and 28.83 mm, respectively. The reason can be explained by following two factors. Firstly, in this stage, the wind speed remains above 3.5m/s and super-cooled water droplets obtain larger kinetic energy and are more likely to collide with the insulator. Meanwhile, the increase of wind speed accelerates the process of heat exchange of water droplets, which is more conductive to the freezing of water droplets and accelerates the growth of ice. The growth rate of d_0 becomes slower with the increase of icing time. Taking d_0 in final stage for example, d_0 of insulators is 5.66, 4, 4.72 mm and 5.07 mm. The reason for this is that with the increase of d_0, the damping effect of super-cooled water droplets carried by the air flow rises and reduces the air velocity on the surface of the insulators. Therefore, the momentum of water droplets also decreases, which weakens icing growth.

(3) d_1 of four types of insulators demonstrates a nonlinear growth with the increase of time, but the growth degree will slow down along with the increase of time. d_1 of four types of insulators is only 13.95, 12.46, 11.74 mm and 9.25 mm respectively, which is far less than that shown in Figure 12(b). The reason can be explained by the fact that ice accretion on the surface of insulators on the leeward side forms by super-cooled water droplets which bypass the rod of insulator and collide with insulator. When water droplets carried by wind bypass the rod of insulator, the velocity dramatically drops leading to the decrease of E, thus there is little ice existed on the leeward side.

IV. CONCLUSIONS

(1) There are considerable differences between the icing formed under artificial environment and that formed under natural environment. The icing formed under the field test is not uniform. And ice mainly exists on windward side of insulator and there is almost no ice on leeward side.

(2) With the increase of time, the ice mass will grow nonlinearly, while the grow degree slows down. Icing of insulators arranged on the windward side is somewhat more serious than that arranged on the leeward side.

(3) The increase of the extended length icicle attached on the surface of insulator shows a nonlinearly growth with the increase of time. The growth degree at the first stage is rapid, while it slows down at other two stages. The increase of the ice thickness of the edge of sheds and the ice thickness of leeward side shows the same trend.

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